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Keywords: livestock; pig manure; solid-liquid separations



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## Article

# Evaluation of Physicochemical Separation Characteristics of Pig Manure According to the Type of Solid-Liquid Separator Processes

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**Abstract:** This study evaluated various solid-liquid separation (SLS) processes used in pig farms for wastewater and livestock manure. SLS is crucial for recycling and purifying pig manure. Seven SLS processes were tested on 11 farms: centrifuge, centrifuge with coagulation agent, belt press with coagulation agent, drum screen, inclined screen, vibration screen, and screw press. Samples collected included raw manure, separated liquid, and solid manure after SLS processing, analyzed for pH, EC, moisture, COD<sub>Mn</sub>, BOD<sub>5</sub>, TN, TP, K, TS, SS, NaCl, and heavy metals. Belt press with coagulation agent showed highest TS and SS reduction (78.8% and 96.9%). For TN and TP removal, belt press and centrifuge with coagulation agents achieved 41.0% and 94.2%, respectively. Belt press with coagulation agent removed 59.4% BOD<sub>5</sub> and 66.0% COD<sub>Mn</sub>. Centrifuge with coagulation agent removed 100% Zn and 98.6% Cu. Drum screen, inclined screen, vibration screen, screw press, and centrifuge without coagulation showed lower removal efficiency for nutrients, solids, Zn, and Cu compared to centrifugal and belt press with coagulation. Centrifugal and belt press with coagulation showed higher efficiency in removing nutrients, solids, and metals. Further studies are needed to understand its impact on linked biological or chemical processes.

**Keywords:** livestock; pig manure; solid-liquid separations

## 1. Introduction

For a long time, livestock manure has been acknowledged as a valuable nutrient resource for plants and crops. However, livestock manure only contributes positively and replaces mineral and chemical fertilizers when it is used properly with a minimal loss of nutrients like nitrogen (N), phosphorus (P), and potassium (K) [1,2]. The P and K in livestock manure are similar to those in commercial fertilizers, but the N content is much lower than that in commercial fertilizers [3]. Excessive application of livestock manure as fertilizer and untreated and/or poorly treated manure causes nutrient leaching and runoff and ultimately pollutes surface and groundwater, salinizes semi-arid regions, results in toxic concentrations of heavy metals, and decreases soil aeration [4,5,6,7]. Before utilizing the manure as fertilizer, it should be treated properly to ensure its environmental safety with high fertilizer values. However, recovering the energy and nutrients from liquid manure is difficult because of its lower concentration of organic matter and nutrients [8,9]. Therefore, liquid manure separations become a key process in nutrient recovery strategies [10]. Pig manure is a combination of pig urine, feces, and water spillage, as well as remains of undigested food, antimicrobial drug residues, and pathogenic microorganisms [11]. It is commonly characterized by a

high content of suspended solids, organic matter, phosphorus, and nitrogen [12], which make it high in density and viscosity. Unlike cow and chicken manure, pig manure is more than 90% liquid, so it has limited options for treatment by composting.

Solid-liquid separation (SLS) is part of organic and inorganic solids removal processes from manure slurry and most commonly separates manure into two streams known as the liquid and solid fractions. The SLS process accelerates the manure treatment practice and reduces the environmental impacts [13]. According to Hjorth et al. (2010) [3], the efficiency of an SLS system depends on (1) the chemical and physical properties of the slurry, (2) the desired end-products, and (3) the potential separation techniques, including pre- and post-treatments and combinations of different techniques. Typically, the separation efficiencies of mechanical SLS processes are between 34% and 68% [14,15]. Because of the operational and environmental benefits, the SLS system is often accompanied by multi-step advanced manure treatment processes to improve subsequent treatment steps and achieve the environmental standards and nutrient recovery targets for livestock manure [11,16]. For pig manure, SLS is a pre-treatment option that helps to separate N-rich liquid from P-rich solids and that allows the separated liquid to be used as a source of N to crops without over-supplying P [17]. Consequently, SLS in the manure pre-treatment process creates high processing efficiency by mobilizing biological processes due to the particulate solids. The high concentration of pig manure in the slurry state can reduce the processing load when solids are effectively removed (separated) by the SLS process. The SLS processes are mainly mechanical pre-treatment processes, but not all of them were designed to perform in the same fashion. The most common mechanical SLS systems are screen separators (inclined screen, vibrating screen, rotating screen), centrifuges (vertical and horizontal centrifuges), and presses (roller presses, belt presses, and screw presses). Landfilling and ocean dumping of livestock manure and food waste have been prohibited in South Korea since 2005 and 2012, respectively [18]. Therefore, several manure treatment technologies have been adopted in farm and public levels and they often consist of several treatment processes (SLS, composting, aeration, anaerobic digestion, liquid fertilization, and purification discharge) coupled with each other.

This study evaluated the separation efficiency of BOD, COD, nutrients (N, P, and K), and heavy metals (Cu and Zn) of various solid-liquid separators used in pig farms.

## 2. Materials and Methods

### 2.1. Sampling Methods for Solid-Liquid Separation (SLS)

The sampling of the influent, effluent, and solid materials of the solid-liquid separation (SLS) was conducted after pre-operation of each device for 5 to 30 minutes, in accordance with the characteristics of the respective equipment. The sampling method adhered to specific regulations and guidelines regarding the turbidity sampling criteria and testing methods for the liquid fraction. For the sampling of the influent, effluent, and solid materials of the SLS, sampling was performed after a pre-operation period ranging from 5 to 30 minutes, depending on the characteristics of each device. In the case of liquid samples, such as the influent and effluent, a T-valve was installed at the inlet and outlet points to facilitate sample collection upon request (Please note that in pig farms where the installation of a T-valve was physically impractical, sampling was conducted directly from the inlet and outlet pipes). The liquid samples were collected by the operator after an arbitrary time determined based on on-site conditions. The influent and effluent samples were collected at the midpoint of the predetermined time interval. Regarding the collection of solid samples, the sampler designated an arbitrary time frame (ranging from 1 to 30 minutes) and employed an appropriate container to collect the entire discharge from the solid outlet of the SLS. The weight of the collected sample was measured on-site, followed by the extraction of a portion of the solid sample from the collection container.

### 2.2. Solid-liquid separation techniques

The samples were collected from 11 pig farms that used seven different kinds of SLS processes. Table 1 shows the sampling site, pig population (head) and the technologies they used while this study was being conducted.

**Table 1.** The list of sampling sites and their solid–liquid separation (SLS) techniques.

Sampling site	Pig (head)	Solid-liquid separation (SLS)	Abbreviations
Pig farm A (Nonsan)	2,000	Drum screen	D/S
Pig farm B (Yeoju)	2,200	(+Screw Press)	
Pig farm C (Gongju)	1,000	Inclined screen	I/S
Pig farm D (Jincheon)	6,000	(+Screw Press)	
Pig farm E (Yeongcheon)	10,000		
Pig farm F (Icheon)	1,600	Vibration screen (+Screw Press)	V/S
Pig farm G (Gumi)	3,000	Screw Press	S/P
Pig farm H (Boeun)	1,000		
Pig farm I (Hapcheon)	2,000	Centrifuge	Cf
Pig farm J (Yeongju)	3,800		
Pig farm I (Hapcheon)	2,000	Centrifuge	Cf (+Cog)
Pig farm J (Yeongju)	3,800	(+coagulation agent)	
Pig farm K (Changwon)	4,200	Belt Press (+coagulation agent)	B/P (+Cog)

The average livestock population was 3,233 heads in surveyed farms and the finishing pig slurry was used for this study. Six out of 12 farms in this study paired screw press with other SLS processes and three farms used coagulation agents. The samples were collected after 5 to 30 minutes of pre-operation based on the characteristics of each solid-liquid separator from individual pig farms. The separated solids were sampled from the solid containers after 30 minutes of solid-liquid separator operation, and then collected solids were mixed uniformly and weighed on site. The influents and separated liquids were collected by installing T-shaped valves on the inlet and outlet. On farms where installing valves was not possible, the influents and treated liquid were collected from the inlet and discharge pipes. The influents and separated liquids were collected when the treated solids were past their half-time. The chemical analysis of the influents, separated liquids, and separated solids consisted of pH, EC, TN, TP, K, TS, SS, NaCl, and heavy metals. The COD<sub>Mn</sub>, BOD<sub>5</sub>, were analyzed for influent and separated liquid, and the moisture content was only analyzed for separated solids. These analyses were conducted according to the standard method for the examination of water and wastewater. The pH and EC were measured by YSI meter (multilab IDS 4010-2, xylem Inc. US). The heavy metal content (Cu, and Zn) was measured using Spectroblue IPS.OES (FMX36, Germany) based on the US EPA method 7476.

The removal efficiency was calculated using the formula below.

$$\eta = \left\{ 1 - \left( \frac{B}{A} \right) \right\} \times 100$$

Where,  $\eta$  : removal rate (%)

A : Concentration before treatment

B : Concentration after treatment

### 3. Results and Discussion

Table 2 shows the changes in physicochemical and nutrient parameters by different SLS processes.

**Table 2.** Changes of physicochemical and nutrient parameters (mean value) by different SLS processes (n=3).

Items	Units	stages	V/S	D/S	I/S	S/P	Cf	Cf (+Co g)	B/P (+Co g)
pH		Influents	6.90	7.08	7.20	7.00	7.28	7.40	7.15
		Separated liquid	6.65	7.23	7.23	6.88	7.25	7.53	7.20
EC	(mS/cm)	Influents	50.10	34.88	22.77	44.63	28.08	29.85	32.65
		Separated liquid	42.60	33.70	21.13	41.05	27.65	17.75	31.90
		(Reduction, %)	(15.0)	(3.4)	(7.2)	(8.0)	(1.5)	(40.5)	(2.3)
NaCl		Influents	1.38	0.68	0.63	2.43	0.72	0.75	0.80
		Separated liquid	1.42	0.67	0.43	2.32	0.69	0.19	0.22
		(Reduction, %)	(-2.3)	(0.5)	(32.0)	(4.7)	(4.9)	(74.6)	(72.9)
TS	(%)	Influents	15.82	5.53	3.47	12.55	4.19	4.68	8.24
		Separated liquid	12.17	4.82	2.78	10.74	3.39	1.50	1.75
		(Reduction, %)	(23.0)	(12.8)	(19.9)	(14.5)	(19.0)	(67.9)	78.8)
SS		Influents	10.42	3.99	2.30	9.42	2.74	3.21	6.43
		Separated liquid	7.92	3.44	1.98	8.66	1.86	1.11	0.20
		(Reduction, %)	(24.1)	(13.6)	(14.0)	(8.1)	(32.2)	(65.5)	(96.9)
TN		Influents	14,933	7,088	3,704	10,787	5,015	5,197	7,852
		Separated liquid	12,973	6,648	3,319	10,471	4,781	3,304	4,631
		(Reduction, %)	(13.1)	(6.2)	(10.4)	(2.9)	(4.7)	(36.4)	(41.0)
TP		Influents	4,277	1,022	793	3,285	650	785	1,603
		Separated liquid	3,874	940	573	2,919	457	46	137
		(Reduction, %)	(9.4)	(8.0)	(27.7)	(11.2)	(29.8)	(94.2)	(91.5)
K		Influents	7,768	3,159	2,487	6,360	2,961	2,873	3,722
		Separated liquid	7,953	3,162	2,400	6,335	2,885	2,139	1511
		(Reduction, %)	(-2.4)	(-0.1)	(3.5)	(0.4)	(2.6)	(25.6)	(59.4)
BOD <sub>5</sub>	(mg/L)	Influents	85,350	30,290	10,229	60,585	21,948	22,825	29,580
		Separated liquid	72,850	27,940	8,894	58,250	20,915	10,525	10,050
		(Reduction, %)	(14.6)	(7.8)	(13.0)	(3.9)	(4.7)	(53.9)	(66.0)
COD <sub>Mn</sub>		Influents	40,527	14,923	7,822	3,0171	11,491	13,287	18,263
		Separated liquid	34,884	14,139	6,977	2,6291	8,295	3,245	4,104
		(Reduction, %)	(13.9)	(5.3)	(10.8)	(12.9)	(27.8)	(75.6)	(77.5)
Zn		Influents	110.4	55.0	33.4	105.0	65.6	65.6	738.0
		Separated liquid	104.6	50.7	28.0	109.8	57.5	ND*	6.8
		(Reduction, %)	(5.2)	(7.8)	(16.0)	(-4.6)	(12.4)	(100.0)	(99.1)
Cu		Influents	66.2	19.5	16.6	56.7	24.3	24.0	47.8
		Separated liquid	65.9	16.8	11.0	57.3	22.1	0.3	0.9



	(Reduction, %)	(0.4)	(13.8)	(33.7)	(-1.1)	(9.1)	(98.6)	(98.1)
*MC (%)	Influents	-	-	-	-	-	-	-
	Separated solid	73.2	68.6	74.7	65.7	47.4	74.0	76.4

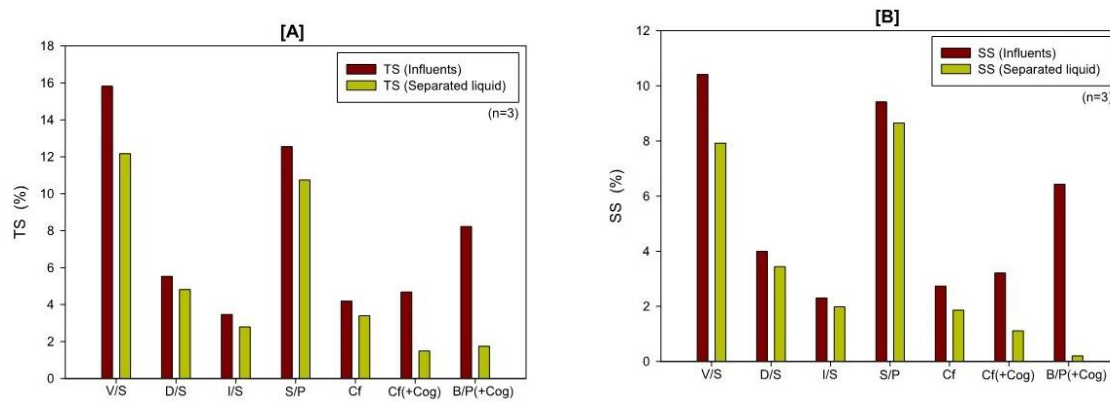
\*MC, moisture contents; \*ND, not detected.

### 3.1. Changes in EC and NaCl content

The different screen mesh sizes from different SLS methods create differences between operation and removal efficiencies of SLS systems and manure characteristics [19]. The pH and EC are two important manure characteristics, especially when manure is used for liquid or compost fertilizer. The changes of pH and EC by SLS processes show similarities with the finding of Jørgensen and Jensen (2009) [20], where separated liquids from the influents showed stable pH changes but variable EC changes. Our values show that the pH units remained at 6.61–8.63, which were near neutral, for 44 samples, while EC varied from 2.57 to 4.47 mS/cm. They also show that the Centrifuge (+coagulation agent) had the highest reduction of EC. The near-neutral pH (6.7 to 7.2 units) and widely varied EC (4.9–17.0 mS/cm) are also reflected in studies by Kumaragamage et al. (2016) [21] and Vanotti et al. (2018) [14]. However, the samples that used coagulation agents showed a little increment in pH that because of the chemical compositions of the coagulant agents but stayed near neutral [11,13,20]. In this study, the pH range of influents and separated liquids did not change much by any of the SLS processes (Table 2). The pH changed from 6.90 to 6.65, 7.08 to 7.23, 7.20 to 7.23, 7.00 to 6.88, 7.28 to 7.25, 7.40 to 7.53, and 7.15 to 7.20 units for the V/S, D/S, I/S, S/P, Cf, Cf (+Cog), and B/P (+Cog) processes, respectively. The electrical conductivity (EC) reduction by Cf (+Cog) of 40.5% was the highest when the influent EC was 29.8 mS/cm and the separated liquid contained 17.8 mS/cm EC. For the V/S, the influents had the highest EC value, 50.1 mS/cm, but it was reduced 15.0% to 42.6 mS/cm after the treatment. The lowest EC removal was observed for the Cf, where EC reduction was only 1.5%, from 28.1 mS/cm to 27.7 mS/cm. On the contrary, B/P (+Cog) with a coagulant agent did not show much EC reduction (2.3%). The NaCl reduction by Cf (+Cog) and B/P (+Cog) with a coagulation agent showed the highest removal efficiency at 74.6% and 72.9%, respectively (Table 2). Among the three screening separator processes, the V/S added up to 2.3% NaCl, I/S reduced 32.0%, and D/S reduced only 0.5%.

### 3.2. Changes of TS and SS contents

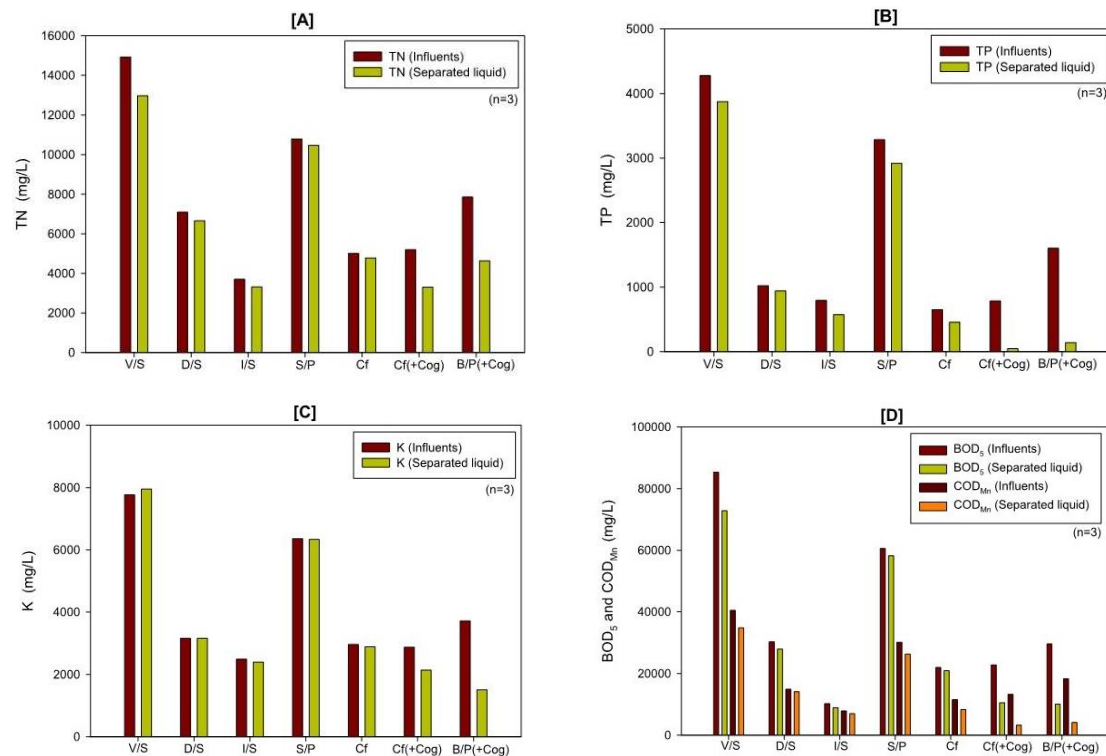
Figure 1 shows the changes in TS and SS by different SLS processes. The B/P (+Cog) and the Cf (+Cog) had 78.76% and 67.94% TS removal efficiency, respectively, the highest. Excepting these two coagulations agents–supported SLS processes, the rest of the SLS processes showed 12.8–23.0% TS removal efficiency. The coagulant-supported SLS processes had the highest SS reduction: 96.9% and 67.94% by B/P (+Cog) and Cf (+Cog), respectively. The Cf process had SS removal efficiency of 32.2%. The rest of SLS processes showed 8.1–24.1% TS removal efficiency. Meanwhile, the moisture in the separated solids was 73.2%, 68.6%, 74.7%, 65.7%, 74.0%, and 76.4% for the V/S, D/S, I/S, S/P, Cf (+Cog), and B/P (+Cog) processes, respectively. However, the Cf process contained the lowest moisture content at 47.41%.



**Figure 1.** Changes in TS (A) and SS (B) by different SLS processes.

### 3.3. Changes in nutrient content (TN, TP, and K), BOD<sub>5</sub>, and COD<sub>Mn</sub>

Comparing the screw press (S/P) with a centrifuge (Cf), several authors found that the centrifuge achieves higher performance [8,10,22]. According to Aguirre-Villegas et al (2019) [15], Cf processes are more effective for the removal of TS, SS, TN, TP, K, BOD<sub>5</sub>, and COD<sub>Mn</sub> than S/P processes. This finding is also reflected in this study (Table 1). Figure 2 shows the changes in nutrient content (TN, TP, and K), BOD<sub>5</sub>, and COD<sub>Mn</sub> by different SLS processes. When comparing Cf process with V/S, D/S, V/S shows better removal of TS, TN, and BOD<sub>5</sub>. The Cf (+Cog) process had a better EC, NaCl, TS, and TP removal efficiency than the B/P process. On the other side, the B/P (+Cog) process had a comparatively better performance for TN, K, BOD<sub>5</sub>, and COD<sub>Mn</sub> removal than the Cf (+Cog) process. The relatively low removal efficiency of TN, TP, and K in separated liquids by mechanical processes without coagulation agents could be because of their higher soluble or dissolved form [13,15,23,24]. The higher TP concentrations in separated liquids and the removal efficiency for B/P (+Cog) are similar to those in a study conducted by Møller et al. (2002) [25]. However, the higher removal efficiency of TN, TP, and TK by Cf (+Cog) and B/P (+Cog) is due to the chemical treatment coupled with mechanical (centrifuge and belt press) treatment, which screened out smaller sized particles [20,26]. The B/P (+Cog) showed the highest TN reduction of 41.0%, where the influents had 7,857 mg/L, and the separated liquid had 4,631 mg/L of TN. The Cf (+Cog) had the second highest TN removal of 36.4%, where the TN reduced from 5,197 mg/L to 3,304 mg/L. However, V/S, D/S, I/S, S/P, and Cf showed 2.9–13.1% TN removal efficiency. The removal of TP had similar results as that of TN. The Cf (+Cog) and B/P (+Cog) processes showed 94.2% and 91.5% of TP removal efficiency, respectively, in separated liquids. However, V/S, D/S, I/S, S/P, and Cf showed 8.0–29.8% TN removal efficiency. The B/P (+Cog) and Cf (+Cog) showed 59.4% and 25.6% K removal efficiency, respectively. The I/S, S/P, and Cf had only 0.4–3.5% removal efficiency for K. Moreover, in the case of V/S and D/S, the concentration of K somewhat increased somewhat in separated liquids. The B/P (+Cog) and Cf (+Cog) showed 59.4% and 25.6% K removal efficiency, respectively. The I/S, S/P, and Cf had only 0.4–3.5% removal efficiency for K. Moreover, in the case of V/S and D/S, the concentration of K somewhat increased in separated liquids. The concentration of COD<sub>Mn</sub> and BOD<sub>5</sub> indicates the presence of oxygen-demanding substances in wastewater and are often used as pollution indicators. In this study, the chemical coagulant agent-supported centrifugal and belt press SLS were able to remove the highest amount of BOD<sub>5</sub> and COD<sub>Mn</sub>. The B/P (+Cog) reduced 66.0% of BOD<sub>5</sub>, and the Cf (+Cog) reduced 53.9% of it, and the concentration of BOD<sub>5</sub> in influents was 29,580 mg/L and 22,825 mg/L, and after treatment in separated liquid that reduced to 10,050 mg/L and 10,525 mg/L, respectively. The removal of COD<sub>Mn</sub> had similar results as that of BOD<sub>5</sub>, comparatively.



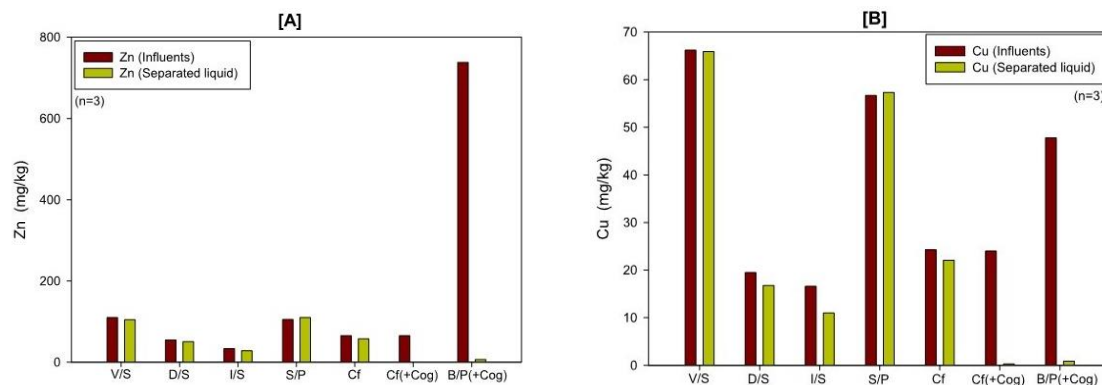
**Figure 2.** Changes in TN (A), TP (B), K (C), BOD<sub>5</sub>, and COD<sub>Mn</sub> (D) by different SLS processes.

The Cf (+Cog) and B/P (+Cog) processes showed 75.6% and 77.5% of COD<sub>Mn</sub> removal efficiency, respectively, in separated liquids. However, other SLS processes showed low removal efficiency for BOD<sub>5</sub> (4.7~14.6%) and COD<sub>Mn</sub> (5.3~27.8%). About 40% of BOD<sub>5</sub> was found in a solid fraction of manure; therefore, after performing SLS, about 60% of the BOD<sub>5</sub> was supposed to remain in the separated liquid [27]. Therefore, the TS and BOD<sub>5</sub> concentration in separated liquids remained in the same sequential order of V/S, S/P, D/S, Cf, I/S. For the coagulation agent-assisted SLS processes, the respective TS and BOD<sub>5</sub> removal was 67.9% and 53.9% for Cf (+Cog) and 78.8% and 66.0% for B/P (+Cog). Similar properties were noticed in changes in COD<sub>Mn</sub>. Each sample that contained higher TS concentrations in both the influent and separated liquids showed higher COD<sub>Mn</sub> concentrations as [28].

### 3.4. Changes in Zn and Cu

Separating of heavy metals such as Zn and Cu from liquid manure before land application reduces the risk of soil contamination [15,29]. Among all the analyzed heavy metal contents, Zn and Cu were found in a higher concentration in the influents. The probable cause is that the pigs get the Zn and Cu from their feeding operation [30]. Figure 3 shows the changes in nutrient content Zn and Cu by different SLS processes. The coagulant assist centrifuge (Cf (+Cog)) and belt press (B/P (+Cog)) were very effective at reducing the heavy metals such as Zn (100% and 98.6%) and Cu (99.1% and 98.1%). These findings are similar to those of Vanotti et al. (2018) [11], which found that a PAM-based mechanical pressing SLS system could remove 88% of Zn and Cu. However, contrastingly, other SLS processes showed low removal efficiency for Cu and Zn. The V/S, D/S, I/S, and Cf showed 5.2~12.4% Zn removal efficiency and 0.4~33.7% Cu removal efficiency, respectively. Moreover, in the case of the I/P process, the concentration of Zn and Cu somewhat increased in separated liquids.





**Figure 3.** Changes in Zn (A) and Cu (B) by different SLS processes.

#### 4. Conclusions

This study has assessed the separation and/or reduction efficiency of various SLS technologies used in pig farms. The centrifugal and belt press processes that used chemical coagulation showed much more removal of nutrient contents, solids, and metals like Zn and Cu. Among all the SLS processes studied, the Cf (+Cog) process showed a 40.5% EC reduction, the highest among all SLS processes. The NaCl was reduced by the Cf (+Cog) and B/P (+Cog) by 74.6% and 72.9%, respectively. The B/P (+Cog) process had the highest TS and SS reduction at 78.8% and 96.9%, respectively. The highest TN and TP removals were 41.0% and 94.2% by B/P (+Cog) and Cf (+Cog), respectively. The B/P (+Cog) removed 59.4% and 66.0% of BOD<sub>5</sub> and COD<sub>Mn</sub>, respectively. The Zn and Cu were reduced by 100% and 98.6% by Cf (+Cog), respectively. However, V/S, D/S, I/S, S/P, and Cf showed lower removal efficiency of nutrient contents, solids, Zn, and Cu than centrifugal and belt press processes that used chemical coagulation. In this study, we found that chemical coagulants made a notable difference in SLS performance for the removal of or changes to different physiochemical parameters of pig manure. Although SLS is an effective pre-treatment process for liquid manure treatment and using chemical coagulants helps remove excess fine solids, nutrients, and heavy metals, further studies are needed to determine how coagulants agents react with other SLS and liquid manure treatment processes.

**Author Contributions:** Data analysis, Writing – original draft, Writing – review and editing, Soo-Ryang Kim, Writing – original draft, Writing – review and editing, Seung-Hyun Park, Writing – original draft, Writing – review and editing, Su-Chan Lee, Writing – original draft, Writing – review and editing, Ji-Won Jung, Writing – original draft, Writing – review and editing, Sang-Hyeon Ahn, Writing – original draft, Writing – review and editing, Kwon-Woong Ham, Project administration, Supervision, Myung-Gyu Lee.

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